Tennessee Water Resources Research Center
Annual Technical Report
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Introduction

Introduction

Water Resources Issues and Problems of Tennessee

Tennessee is fortunate to have what many consider to be an abundant and good quality water supply. Historically, federal government agencies, such as the Tennessee Valley Authority (TVA), Army Corps of Engineers, Natural Resource Conservation Service, U.S. Geological Survey and others, have been the primary contributors to the management and monitoring of water resources. In recent years, however, the State, through the Tennessee Departments of Environment and Conservation, Wildlife Resources, Agriculture and others, have begun to develop a more active and aggressive role in the management and protection of these resources. The State has moved to establish an integrated and coordinated policy and administrative system for the management of water resources in Tennessee.

While the situation is improving, there remain many of the additional types of water problems. Although the overall supply of water is adequate, the distribution is still not optimal. Local shortages occur during dry periods. The summer of 2007 was a particularly hot and dry one. During this period over 35 water districts out of a total of 671 public systems in Tennessee experienced lesser degrees of difficulty in supply water. Beginning in 2006 and continuing on through the summer of 2008, Tennessee experienced another major drought period which severely strained the water supplies of many communities across the state. In recent years, many of the small municipal water suppliers and utility districts that rely on wells, springs, or minor tributaries for their water sources continue to face severe water shortage problems. All across the state many private, domestic, and commercial use wells have become severely strained, forcing users to seek alternative sources of water. Providing an adequate supply of water for industrial, commercial, and domestic uses and the protection of these surface and groundwater resources are of major concern in all regions of the state and vital to the economic development and growth of the state.

Groundwater presents a particular challenge in Tennessee. Over 50% of the population of Tennessee depends on groundwater for drinking water supply. In West Tennessee, nearly all public suppliers, industries, and rural residents use groundwater. However, not enough is known about the quality and quantity of groundwater in the state, and consequently, maximum benefit from and protection of this resource cannot be easily accomplished. More information about the quality of the state's groundwater, particularly about the potential impact of recharge areas, is needed in order to develop an effective management and protection program for this valuable resource.

There is also the problem of potential contamination of groundwater from agricultural and urban non-point sources. The "fate and transport" of agricultural chemicals (herbicides and pesticides) and toxic substances in groundwater is a problem area that must be addressed if the state's groundwater protection strategy is to be effective in protecting this vital resource.

Although the danger of large-scale, main-stem flooding is controlled by mainstream and tributary dams that have been constructed by TVA and the Army Corps of Engineers, localized flooding and even general flooding in unregulated watersheds remain substantial problems across the state. A lack of effective local floodplain management land-use controls is apparent in West Tennessee, where related problems of excessive erosion, sedimentation, drainage, and the loss of wetlands constitutes what many consider to be the greatest single water resource issue in the state from an economic and environmental point of view. Effective regulation of private levee design, construction, maintenance, and safety is needed.

Water quality problems continue to persist from past industrial practices, from the surface mining of coal and other minerals (especially from abandoned mines), from agricultural and urban nonpoint sources and from improperly planned, designed and operated waste disposal sites. As has been the situation in the past, the state's program for the construction of municipal wastewater treatment facilities and improved operation and management of the facilities have experienced numerous set-backs due to shortfalls in funding and administrative delays. In major urban areas that have combined storm and sanitary sewers, urban storm water runoff causes increased pollution and, during periods of wet weather, bypasses treatment facilities, which allows raw sewage to enter receiving waters untreated. Tennessee cities, both large and small, are concerned about current (and future) impacts of the new NPDES storm water discharge permit requirements on clean up needs and costs. In certain regions of the state, failing septic fields and the practice of blasting bedrock for new septic fields are serious threats to surface and groundwater resources.

There are existing programs which can address many of these problems. However, some problems do not have easy solutions. Additional research can also play a role in understanding and solving these problems, but the greatest impediments are the lack of agreement between competing interests and a shortage of financial support for existing programs. From the viewpoint of the State government, the legal, institutional, and administrative aspects of water management are major concerns. The state is still working to develop new policy and to refine administrative structure for the effective management of its water resources.

To address the problems and issues of effective water resources management in the state of Tennessee, a truly interdisciplinary and well-coordinated effort is necessary. The Tennessee Water Resources Research Center has the capability and organization that can call upon the diverse set of disciplinary expertise necessary to address the key water issues of the state and region.

The Tennessee Water Resources Research Center: Overview of Program Objectives and Goals:

The Tennessee Water Resources Research Center serves as a link between the academic community and water-related organizations and people in federal and state government and in the private sector, for purpose of mobilizing university research expertise in identifying and addressing high-priority water problems and issues and in each of the respective state regions.

The Tennessee Water Resources Research Center, located at the University of Tennessee, is a federally-designated state research institute. It is supported in part by the U.S. Geological Survey of the U.S. Department of Interior under the provisions of the Water Resources Research Act of 1984, as amended by P.L. 101-397 and 10 I - 1 47. The Act states that each institute shall:

I. plan, conduct or otherwise arrange for competent research that fosters the entry of new research scientists into the water resources fields; the training and education of future water scientists, engineers and technicians; the preliminary exploration of new ideas that address water problems or expand understanding of water and water-related phenomena, and the dissemination of research results of water managers and the public.

II. cooperate closely with other colleges and universities in the state that have demonstrated capabilities for research, information dissemination, and graduate training, in order to develop a statewide program designed to resolve state and regional water and related land problems.

In supporting the federal institute mandate, the TNWRRC is committed to emphasizing these major goals:

1. To assist and support all the academic institutions of the state, public and private, in pursuing water resources research programs for addressing problem areas of concern to the state and region.

2. To provide information dissemination and technology transfer services to state and local governmental bodies, academic institutions, professional groups, businesses and industries, environmental organizations and others, including the general public, who have an interest in water resources issues.

3. To promote professional training and education in fields relating to water resources and to encourage the entry of promising students into careers in these fields.

4. To represent Tennessee in the Universities Council on Water Resources, the American Water Resources Association (including Tennessee Section), the Water Environment Federation, the American Water Works Association, the International Erosion Control Association, the Soil and Water Conservation Society, the Lower Clinch Watershed Council, the ORNL-TVA-UT Research Consortium and the National Institutes for Water Resources (NIWR).

To work with these and other associations and with state, local and federal government agencies dealing with water resources in identifying problems amenable to a research approach and in developing coherent programs to address them. Particularly, to cooperate with the other state NIWR institutes and their regional groupings for assisting the U.S. Geological Survey in developing a national water resources management strategy.

In fulfilling the Center's major goals indicated previously, TNWRRC emphasizes the application of Section 104 grant and required matching funds for primarily supporting the research and training/education needs of the state. While the information dissemination and technology transfer portion of the Center's overall program does not receive direct or significant section 104 funding, this is accomplished primarily from the research and training activities of the Center from other funding sources--state, private, or non-profit. The Center recognizes that education and training, research, and information transfer are not independent objectives or are not mutually exclusive. Instead these goals are achieved through the administration of a coordinated, fully-integrated program within the limitations of the resources available to the Center.

Research Program Introduction

None.

Evaluation of Bioretention Practices for Effective Stormwater Management and Treatment: A Laboratory to Field Study

Basic Information

Title:	Evaluation of Bioretention Practices for Effective Stormwater Management and Treatment: A Laboratory to Field Study
Project Number:	2011TN78B
Start Date:	3/1/2011
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	Second, Knox County, Tennessee
Research Category:	Water Quality
Focus Category:	Sediments, Non Point Pollution, Water Quality
Descriptors:	Stormwater Managemnet; Sediment; Infiltration; Bioretention; Water Quality
Principal Investigators:	Andrea Ludwig, Daniel Yoder

Publications

1. Ludwig, Andrea, R.A. Hanahan, R. Arthur, and T, Gangaware, 2013,Retrofitting Stormwater Infrastructure and perceptions in a Conventional Suburban Residential Development in East Tennessee, "in" Proceedings of the Twenty-Third Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN. 2B-6.
2. Ludwig, Andrea, M. P. Massey, and K. Neff,2013,Sate of LID in Tennessee, "in" Proceedings of the Twenty-Third Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN., 2A-16.

Evaluation of Bioretention Practices for Effective Stormwater Management and Treatment: A Laboratory to Field Study

Statement of Critical Regional or State Water Problems:

The leading cause of impairment in streams in the US is habitat alteration, which is a direct impact of sedimentation. Sediment pollution from urban areas has been shown to mostly come from failing streambanks that have eroded under increased bank shear stress. This increased shear stress is a result of the flashy hydrology that is characteristic of urban settings and is identified as one of the symptoms of the "urban stream syndrome," which describes the ecological degradation of streams draining urban landscapes (Walsh, Roy et al. 2005). Other symptoms are elevated concentrations of nutrients and pollutants, altered channel morphology, and reduced biotic richness.

There are over 60,000 stream miles in the State of Tennessee, and of the approximately 30,000 miles that have been assessed, only 54% were supporting all designated uses (Denton, Graf et al. 2010). This indicates that almost half of Tennessee streams exhibit degraded water quality. The leading causes of pollution in Tennessee streams and rivers are sediment/silt, habitat alteration, pathogens, and nutrients. Exacerbating this issue is a 60% loss of wetland areas in Tennessee as determined through historic data (Denton, Graf et al. 2010), which decreases land area that has the capacity to hold and treat flood waters and removes ecosystem services crucial to good water quality.

Statement of Results or Benefits:

The first phase of this project identified the following outcomes from the stated objectives: 1) a characterization of pollutants of concern for ecological function in surface waterways transported by stormwater from a residential development, 2) laboratory data to support recommendations of media layers for bioretention practices, 3) quantity and quality treatment efficiencies based on loading reductions due to BMPs in the Cedar Crossings development, and 4) begin a water quality monitoring database on the capacity of bioretention practices to meet infiltration requirements of permits for use by stormwater professionals.

The second phase will address the needs of the education and BMP adoption goals of the project team for Cedar Crossing neighborhood. The specific outcome will be a Home Stormwater Assessment Tool for assisting homeowners and stormwater professionals in selecting and implementing small-scale stormwater BMPs that will be transferable to other residential communities.

As of December 31, 2011, progress has been made on the stated objectives:

1) Characterization of pollutants: Two monitoring stations were installed in the project neighborhood to collect flow-weighted water quality samples and flow data during storm events. The first station is located at a drop inlet storm drain near the common space that is slated for the large-scale bioretention facility and sampling from a drainpipe that carries stormwater from an approximately 4-acre sewershed. This sewershed is representative of the single-family residential neighborhood. The second station is

located at the inlet to the detention basin that receives the majority of the runoff produced from the single-family units and condominiums. Stormwater hydrographs were developed for ten storm events between June and December 2011. Water quality analyses were performed on samples from five of these ten events. Additional sites were identified for grab water sampling in order to characterize stormwater at specific locations throughout the neighborhood.

2) Laboratory data for media: A prototype design was created for bioretention mesocosms that would be used in bench-scale experiments. Three different media mixtures and carbon sources were identified as test treatments in experiments and selection of appropriate instrumentation to measure storage volume has begun. A preliminary experiment was conducted to measure the amount of leachable nutrients from commonly used and readily assessable mulches.

3) Treatment efficiency determination: Treatment efficiencies will be characterized once BMPs are installed in the project neighborhood, beginning in 2012.

4) BMP water quality monitoring database: A database was conceptualized to include the following data on stormwater BMPs in Tennessee: site location (geographic coordinates), picture, stormwater source, inflow water quality data, outflow water quality data, storage, and other pertinent design parameters and site conditions.

This project neighborhood will serve as a long-term study location for ubran hydrology and stormwater management research. Additionally, it will be a demonstration of the retrofit of individual lots and neighborhood common spaces with small-scale stormwater practices. This demonstration is timely due to increasing regulations on stormwater from urban areas and the motivation of individual homeowners to minimize their impacts on the environment. The long-term goal of project cooperators is to increase BMP adoption by homeowners and condominium owners to create a model neighborhood community for retrofitting failing or substandard stormwater management controls. In order to accomplish this, residents must be educated on watersheds and stormwater management, potential impacts to water quality due to urban development, and effective solutions. An action plan was created by project cooperators to outline the approach, which is: 1) collect background data and anecdotal information regarding water quality and stormwater management in the area, 2) educate homeowners on the issues and needed solutions, 3) identify external cost-sharing opportunities for homeowners interested in lot-scale BMPs, 4) create a standardized method for assessing the stormwater footprint and appropriate BMPs for individual homes (the Home Stormwater Assessment), 5) identify and train needed professionals for stormwater BMP installations, 6) assist in neighborhood-scale implementations, and 7) continue to monitor hydrology and water quality throughout retrofit.

In October 2011, Cedar Crossing residents attended a 2-hr educational workshop from the *Tennessee Yards and Neighborhoods* team. Participants were given information about their home watershed (Beaver Creek), sources of stormwater in residential settings, and lot-scale BMPs to retain and filter stormwater. In phase two of this project, we will develop a 2-step Home Stormwater Assessment and pilot its use with residents of Cedar Crossing and the condominiums.

As of December 2012, progress was made on the following objectives:

1) Characterization of pollutants: Runoff rates and total volume accumulated per storm event were measured as to continue to characterize small-scale residential sewershed response to rainfall events. Water quality analyses for pollutants in stormwater runoff grab samples has been scaled down to specific storm events (approximately once a season).
2) Laboratory data for media: Bench-top experimental set-up was assembled to include 16 mesocosms, influent reservoir, effluent sampling hoses, and sample collection reservoirs. Drip diffusers were inserted along tubing running from the influent reservoir, and flow rate calibration was performed. Preliminary tests were conducted to determine the effect of course sand material selection (dredged river sand vs. manufactured sand from limestone) on effluent pH. Initial results indicate that effluent from manufactured sand infiltration practices are higher in pH than that coming from dredged river sand applications. Further studies will be conducted on innovative soil amendments for rain garden applications.
3) Treatment efficiency determination: Field determination of treatment efficiencies for bioretention practices will be limited due to the fact that only 3 lot-scale practices were implemented in the neighborhood due to grant funding reallocation. While total runoff volume and flow rate will continue to be monitored at the outlet of the 38-acre subdivision, significant change in overall hydrology is not expected due to the limited amount of on the ground practices.
4) BMP water quality monitoring database: Principle investigators were successful in obtaining state funding for work towards a green infrastructure design manual. In cooperation with this project, work towards the database continues to occur. The database will be established in 2013 and contribute towards state-sponsored documents.

In 2012, three lot-scale bioretention practices (rain gardens) were designed and implemented in the test neighborhood through state funding. Through this part of the project, we were able to pilot our homeowner educational tool, "Rainwater: Your Liquid Asset. A Home Stormwater Exercise." This tool is a 6-page Extension publication that steps a homeowner through an activity that maps the flow of stormwater on their property while educating them on how runoff is generated, where it goes, and how they can use lot-scale practices to minimize their footprint. This tool is currently in press at the UT Extension Communications Department. This will be a web publication that is accessible by anyone online and marketed for use specifically through county Extension offices and local Tennessee municipal governments. We have also used this publication as a pre-workshop activity for homeowners that enroll in our rain garden workshops. Participants are invited to map their pervious and impervious surfaces, downspouts, and stormwater conveyances, and then bring this to the workshop in order to help guide them towards successful designs and implementation.

Nature, Scope and Objectives of Research:

The nature of this research is to investigate to composition of stormwater runoff from an urban residential development and into an impaired waterway. In addition, the proposed research will study how variables associated with the media of bioretention practices will affect performance and evaluate field-scale practices. The scope of the project is bench-scale experimentation with controlled variables and field-scale monitoring of engineered solutions for stormwater management. Field data collection will be limited to a single neighborhood; however, this will begin the formation of a database of infiltration BMP monitoring data. Since success of the overall project hinges on the involvement and commitment of property owners in the study development, we reserve the right to change the location to another development in the face of currently unforeseen barriers in Cedar Crossings. If necessary, the new location would be selected based on the potential for technology transfer to other developments and pollutant reduction to Beaver Creek.

The objectives of this research are to 1) characterize stormwater volume and concentrations of pollutants of concern being transported from Cedar Crossings residential neighborhood and into Beaver Creek; 2) determine the effects of bioretention design variables (layer media composition, layer thickness, and saturation hydroperiod) on BMP performance through bench-scale laboratory column studies; 3) monitor the effectiveness of field-scale bioretention practices for peak flow and pollutant attenuation in Cedar Crossings; and 4) evaluate the effectiveness of selected bioretention practices for meeting infiltration requirements of new municipal stormwater management permits and demonstrate potential stormwater retrofit design. The larger project that is funding the BMP installations requires that technology transfer to other parts of the state be achieved, and therefore, we will adapt these broad objectives to the project as specific BMP designs are identified as practical for residential neighborhood stormwater retrofit.

Methods, Procedures, and Facilities:

The methods employed for this study on bioretention stormwater practices include: 1) sampling stormwater conveyances through grab samples during storm events and analyzing for sediment, nutrients, and other pollutants of concern; 2) a bench-scale factorial study using laboratory columns and simulated storm events (Hsieh, Davis et al. 2007) to examine the effects of bioretention design variables (layer media composition and thickness, and internal storage zones) on BMP performance; 3) field monitoring of BMPs with automated samplers for capturing timed and flow-composited samples and analyzing for load reduction of pollutants of concern; and 4) measurement of BMP outlet hydrograph and total precipitation to evaluate feasibility of practices to infiltrate 100% of the first inch of rainfall following a 72-hr dry period. Pollutant and runoff volume reductions will be determined through field water quality sampling for pollutant removal and flow measurements based on load estimations (Johnes 2007).

As the field-scale components of the study develop through the anticipated adoption of infiltration practices at the home-owner level, the contributing impervious surface area will decrease over the project timeline. This is expected to have an effect on the outflow from the development. To understand the hydrologic impact of BMP adoption, we will monitor stormwater flow in the storm sewer system and relate this to the changing *retention capacity* of the development. The *retention capacity* is the degree of connection of impervious surfaces to streams (Walsh, Roy et al. 2005). We will examine the relationship between stormwater hydrology and retention capacity over time.

Additionally, total suspended solids and turbidity data will be collected simultaneously during variable size storm events. Regression analysis will be performed to create a relationship between TSS and turbidity as to allow for future loading estimates from turbidity in disturbed urban soils in Eastern Tennessee.

The second phase of this project will engage homeowners and facilitate the adoption of lot-scale stormwater BMPs through the development and use of a Home Stormwater Assessment tool. This tool will be created through the work with Cedar Crossing residents and it's use piloted throughout the neighborhood. The overall goal is to create an easy-to-use tool that will be transferable to residential areas across the state (and region). The tool will have two steps: I) identifying the stormwater flow path, imperviousness, and potential pollutants (to be completed by homeowner), and II) on-site analysis for appropriate BMP selection and placement (to be completed by stormwater professional). Step I will not only build the capacity of the homeowner to understand the link between their home and water quality in their watershed, but also

Related Research:

Bioretention is an emerging stormwater best management practice for runoff reduction and peak attenuation and an element of better site design for residential developments (Johnes 2007). The mechanisms for stormwater management and treatment through bioretention are infiltration, evapostranspiration, media filtration, increase groundwater recharge, vegetation uptake of nutrients, media sorption of pollutants, and microbial conversion of nutrients. Secondary pollution reduction benefits are experience through reducing streambank erosion by reducing total runoff volume and peak flows.

In published studies, bioretention was an effective management practice for reducing runoff volume (Cosgrove and Bergstrom 2001; Davis 2008), attenuating heavy metal (Mason, Ammann et al. 1999; Davis, Shokouhian et al. 2001), and decreasing sediment loading in receiving waterways (Davis, Shokouhian et al. 2006); (Hsieh and Davis 2005). However, there is great variability in results reported for nutrient retention through bioretention (Table 1). Much of the variation may be attributed to design characteristics, such as hydraulic loading, media composition, and outlet design. Bioretention practices without underdrains (usually referred to as rain gardens) have also shown great hydraulic and pollution retention potential when designed to capture the first inch of runoff (typically required by state stormwater permits). Saturation zones in bioretention without underdrains decreased redox potential, which increases nitrate attenuation through denitrification (Davis, Shokouhian et al. 2006). Bioretention soil media has also shown to effect pollutant removal efficiencies (Johnes 2007). More research needs to be conducted to understand the effect of bioretention media mix, design layer depths, and internal storage zone hydroperiod on treatment performance for nutrient reduction.

Study Location	Bioretention Layers*	Nutrient Species	Average Inlet Concentration (mg/L)	Reported Mass Removal Effeciency (%)	Citation
Lab	Mulch, sand, sandy loam	TP	3.06	63-85	(Hsieh, Davis et al. 2007)
Lab	Mulch, topsoil, sandy loam	DP TKN NO_3	0.6 4.0 2.0	81 68 24	(Davis, Shokouhian et al. 2001)
Lab	Mulch, sandy loam	TP TKN NO_3	0.44 3.5 0.39	70-85 55-65 <20	(Davis, Shokouhian et al. 2006)
CT	Mulch, sandy loam, underdrain	NO_3 NH_3 TKN TP TN	0.9 0.04 0.6 0.015 1.6	67 82 26 -108 51	(Dietz and Clausen 2006)
NC	Mulch, soil, underdrain	TN NO_3 TKN TP OP	1.27 0.5 1.0 0.11 0.09	40 75 -4.9 -240 -9.3	(Hunt, Jarrett et al. 2006)

* TN – total nitrogen; TP – total phosphorus; OP – orthophosphate; NH_3 – ammonia; NO_3 – nitrate; DP – dissolved phosphorus; TKN – total kheldal nitrogen.

An Evaluation of Floodplain Forest Land Use Dynamics, Ecosystem Services and Conservation Policies in West Tennessee Watersheds

Basic Information

Title:	An Evaluation of Floodplain Forest Land Use Dynamics, Ecosystem Services and Conservation Policies in West Tennessee Watersheds
Project Number:	2011TN79B
Start Date:	3/1/2011
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	Second,Knox County, Tennessee
Research Category:	Social Sciences
Focus Category:	Wetlands, Economics, Ecology
Descriptors:	Ecosystem Services; River Restoration, Floodplain Forest
Principal Investigators:	Donald Hodges

Publications

1. Hodges, Donald; and Donald Grebner, 2013, Dealing with uncertainty and risk in uneven-aged hardwood management in the southern Appalachians of the United States, "in" International Symposium on Socio-economic Analyses of Sustainable Forest Management, International Union of Forestry Research Organizations, Prague, Czech Republic, pp. 35-42.
2. Hodges, Donald; and Donald Grebner, 2013, Dealing with uncertainty and risk in uneven-aged hardwood management in the southern Appalachians of the United States, "in" International Symposium on Socio-economic Analyses of Sustainable Forest Management, International Union of Forestry Research Organizations, Prague, Czech Republic, pp. 35-42.
3. Hodges, Donald; and D. Stuart Hale,2014,Decison support System to assess the role of ecosystem services in adapting to shifting framework conditions, "In" Proceedings, International Symposium of International Union of Forestry Research Organizations, Combined Conference of Research Groups 3.08 (Small-Scale Forestry) and 4.05 (Managerial Economics and Accounting) E. Schiberna and M. Stark, editors pp. 87-92.

Statement of Critical Regional or State Water Problems:

The watersheds of West Tennessee contain a significant number of streams that have been listed by the Tennessee Department of Environment and Conservation on the 303(d) list as impaired, meaning they do not meet designated beneficial uses including biological integrity [40 CFR Part 130; TCA §69-3-101 and TDEC Rules Chapter 1200-4]. Due to historic channel alteration and riparian habitat alteration associated land use change over the past century, a large number of these impaired streams have been impacted by excessive siltation. In addition to local stream restoration and floodplain reforestation initiatives planned to support Total Maximum Daily Load implementation and watershed restoration, significant local attention is being devoted to developing ecosystem restoration strategies and sustainable management plans for West Tennessee rivers.

Most notably, the State of Tennessee submitted a formal request to the U.S. Army Corps of Engineers to reevaluate management options to control flood risk in the Obion and Forked Deer watersheds. This led the Corps of Engineers to publish a Notice of Intent in the National Register in May 2009 to prepare a Draft Supplement No. 2 to the Final Environmental Impact Statement for the West Tennessee Tributaries Project General Reevaluation. While the National Environmental Policy Act scoping process was initiated in late 2009, a number of local and national organizations voiced concern for the project and its potential implications for the west Tennessee ecosystem. Therefore, empirical evaluation of floodplain forest dynamics in West Tennessee watersheds can serve both to inform the scientific community as to the landscape-scale changes that have taken place throughout the region in past decades, and to guide public policies regarding land management and water resource planning throughout the region.

Statement of Results or Benefits:

While previous studies have explored the theoretical alternatives for restoring ecosystem services in agricultural watersheds, fewer studies have evaluated actual land use dynamics and how these are related to the provision of ecosystem services. Great potential exists for applying similar techniques to other agricultural watersheds throughout the Southeast. Therefore, this project will produce a methodology that incorporates economic values into estimating spatial and temporal changes in floodplain ecosystem service provision.

Given recent progress made by ecologists in recognizing the role of floodplain forests for river sustainability (Stanturf et al. 2009), appropriate attention must be placed on evaluating natural resource policies and developing management strategies that support floodplain restoration. Additionally, emerging interest in large-scale restoration of fluvial ecosystems is dependent upon the analysis of how past policies have influenced West Tennessee floodplains. Perhaps more importantly, the proposed re-conceptualization of the West Tennessee Tributaries Project by the US Army Corps of Engineers has increased focus on understanding how policies have impacted floodplain ecosystems in the region, and how management strategies can be successfully adapted to ensure the sustainability of river systems for multiple uses. Thus, the results provided by this study will hold a number of practical implications for floodplain ecosystem restoration in West Tennessee, and for river conservation policies throughout the world.

Nature, Scope and Objectives of Research:

In order to develop a more complete understanding of the functions, distribution, and dynamics of floodplain forests in West Tennessee, a multi-faceted study of the legal, political, and biophysical framework must be initiated (King et al. 2009). Rather than simply focusing on one component of regional floodplain ecosystems, this study will explore the relatively recent evolution of management paradigms, with particular focus on how shifts in natural resource policies have impacted the distribution of floodplain forests in West Tennessee, and subsequently how these land use dynamics are connected to the flow of ecosystem services from both public and private lands in the region. Therefore, a comprehensive research approach is proposed which incorporates multiple methodologies to better understand west Tennessee floodplain management issues, and to aid in developing conservation policies that promote ecosystem restoration and sustainable management of natural resources throughout the region.

Objective #1: Develop a comprehensive inventory of geospatial data documenting the distribution of floodplain ecosystems in West Tennessee.

Both Defries & Eshleman (2004) propose the integration of multiple disciplines into the emerging study of landscape change, particularly focusing on the implications of land use dynamics on hydrological function. As demonstrated by Hodges et al. (1998), integrating multiple modeling methodologies can aid in projecting future land use scenarios. Additionally, previous research by Carver et al. (2006) reveals the immense potential for applying spatial analysis techniques to evaluate specific forest policy initiatives, revealing meaningful information for restoration planning and natural resource decision-making in channelized watersheds in Southern Illinois.

A comprehensive geospatial database will be constructed that incorporates existing data sources on regional hydrography, stream quality, biodiversity and wildlife habitat, vegetation classification, land use, soil resources and other relevant data. The data also will be developed to include information needed to assess the level of ecosystem services in the watershed.

> **Progress To Date:** The geospatial database for the study area has been completed, including the data related to different ecosystem services, which have been gathered and processed. The data requirements for the InVEST model have been assessed and the data for each model have been compiled and processed. Carbon storage and sequestration, habitat quality and rarity, nutrient retention, water quality regulation, and timber production will be considered to assess the distribution of floodplain ecosystems using the InVEST model. For carbon storage and sequestration model, the land use and land cover raster dataset was obtained from National Land Cover Database. The carbon pools for aboveground, belowground, soil, and dead organic matter for each land uses and the current harvesting rate have been collected from available literature. The digital elevation model and soil depth, precipitation, evaporation, land use, and watershed data have been collected for the nutrient retention model. The digital elevation model is available for sediment retention model and rainfall erosion index and soil erodibility are other additional data required to run the model.

In order to assess the changes in the land use due to channelization, the available land use data for the year 1992, 2001, and 2006 have been obtained from the National Land Cover Database. Landsat images were obtained from U.S. Geological Survey (USGS)'s Global Visualization Viewer) to identify the chances in the land after the channelization before 1990s. Those Landsat images were classified into different land use categories applying Maximum likelihood classification in ArcGIS 10.

Objective #2: Evaluate the political and legal factors that have influenced West Tennessee river system management.

Because regional river management strategies have a long and complex history (Smith et al. 2009), it is necessary to develop both a background as to the public policies that have guided floodplain management in West Tennessee, and a deep understanding of the legal guidance that has directed river conservation strategies in the past few decades. Therefore, this study will include an analysis of the policies that have directed river management, including the Flood Control Act of 1948, the Fish and Wildlife Coordination Act, the National Environmental Policy Act and the Clean Water Act; as well as the legal cases that have influenced management activities and subsequent mitigation efforts such as *National Ecological Foundation v. Alexander, et al.*, Civil Action No. 78-2548-H, and *Akers v. Resor, et al.* Civil Action No. C-70-349.

The implications of recent federal and state policies designed to support stream ecosystem restoration must also be considered as an essential element of floodplain forest conservation policy. Farm Bill programs impacting private lands management, such as the Conservation Reserve Program and the Wetland Reserve Program, obviously play a great role in private land management in West Tennessee (Bridges 2010). Additionally, state stream and wetland protection legislation and associated watershed restoration initiatives will also be examined along a temporal gradient to examine how river management paradigms have evolved in West Tennessee over the past few decades. The evolution of the West Tennessee River Basin Authority's strategies for environmentally-sensitive stream maintenance and floodplain restoration, which differ significantly from earlier support for channelization (Johnson 2007), will also be examined as part of this objective.

A wide variety of data are available detailing the early scoping phases for the development of an additional supplement to the Environmental Impact Statement that would allow for the reformulation of the West Tennessee Tributaries Project as a flood control initiative. Scoping documents, proposed resource management plans and written comments received during the scoping process will be examined to better understand the complexities of floodplain management in West Tennessee.

Progress To Date: The publicly available documents have been obtained and have reviewed to develop a comprehensive assessment of the role that past and current federal and state policies have played in river management and stream ecosystem restoration. To build upon the lessons learned from the document analysis, key informant interviews are being administered to individuals knowledgeable about West Tennessee rivers issues and will be completed by August.

Objective #3: Explore spatial and temporal changes in the distribution and flow of ecosystem services derived from West Tennessee floodplain forests and wetlands.

Smith & Rosgen (1998) identified several questions for future researchers to explore as a means of informing West Tennessee river conservation policies, including the societal values associated with alternative floodplain management systems. Because of the immense ecological, economic and social values placed upon floodplain forests, the development of a methodology that quantifies the values associated with land use change in west Tennessee floodplains will provide much-needed guidance for restoration planning. Consequently, a key objective of this study is to examine the spatial and temporal changes in ecosystem service production associated with West Tennessee floodplain land use dynamics. Tremendous spatial variability is exhibited in the ecological characteristics of West Tennessee floodplains.

Progress To Date: As described for Objective 1 Progress above, the data for Objective 3 has been collected and processed. This resulted in two presentations at the International Union of Forest Research Organizations, Working Group 4.05.00 annual meetings (Hodges and Grebner 2013, Hodges and Hale 2014). An additional presentation is scheduled for the International Union of Forest Research Organizations World Congress in October as well (Hodges et al. 2014).

<u>Related Research</u>:

Multiple researchers associated with the University of Tennessee have applied a variety of expertise to the analysis of water resources and associated floodplain ecosystem research in West Tennessee over the past few decades. Early evaluation of the implications of river channelization throughout the Obion and Forked Deer systems helped to inform local decision-makers as to the cost of natural resource management alternatives (Smith & Badenhop 1975). More recent research projects have also included multiple evaluations of the influence of excess sediment loading on floodplain forest composition (Pierce & King 2008), and also the implications of forest habitat dynamics on wildlife communities (Summers & Gray 2009). Additionally, the geomorphological research of Smith, Diehl et al. (2009) is also helping to guide river restoration throughout the region.

While great attention has been placed regionally on the integration of ecosystem services (Lant et al. 2005) and associated economic implications into river resource management planning (Lockaby 2009), significant opportunity remains to explore the implications of natural resource policies on West Tennessee rivers and floodplains. The results of this project have served as the foundation for a research proposal submitted to the USDA National Institute for Food and Agriculture competitive grants program for 2014.

Award--Development of Water Quality Model for Regional Loadings

Basic Information

Title:	Award--Development of Water Quality Model for Regional Loadings
Project Number:	2011TN86S
Start Date:	4/13/2011
End Date:	12/31/2013
Funding Source:	Supplemental
Congressional District:	Second
Research Category:	Water Quality
Focus Category:	Water Quality, Conservation, Models
Descriptors:	
Principal Investigators:	Timothy Gangaware, Carol P Harden

Publications

1. Tran, Liem T.,Robert V. O'Neill, Elizabeth R. Smith, Randall J.F. Burns, and Carol Harden, 2013, Application of Hierarchy Theory to Cross-Scale Hydrologic Modeling of Nutrient Loads, Water Resources Management. Springer, New York, NY, 1:1-17.
2. Tran, Liem T., and Robert V. O'Neill, 2013, Detecting the Effects of Land Use/Land Cover on Mean Annual Streamflow in the Upper Mississippi River Basin, USA. Journal of Hydrology, "in preparation".
3. Tran, Liem T., and Robert O'Neill,2013, Hierarchy and Cross-Scale Hydrologic Modeling, "in" Annual Meeting of Association of American Geographers, Los Angles, CA., pp.236-243.
4. Tran,Vi,and Liem Tran,2013,Geospatial Regression Models for Regional and Sub-Regional Mean Annual Streamflow, "in" Annual Meeting of Association of American Geographers, Los Angles, CA., pp.244-251.
5. O'Neill, Robert and Liem Tran,2013,Cross-Scale Hydrologic Modeling for Annual Sediment Load, "in" Annual Meeting of Association of American Geographers, Los Angles, CA., pp. 252-261.
6. Tran, Liem T.,Robert V. O'Neill, Elizabeth R. Smith, Randall J.F. Burns, and Carol Harden, 2013, Application of Hierarchy Theory to Cross-Scale Hydrologic Modeling of Nutrient Loads, Water Resources Management. Springer, New York, NY, 1:1-17.
7. Tran, Liem T., and Robert V. O'Neill, 2013, Detecting the Effects of Land Use/Land Cover on Mean Annual Streamflow in the Upper Mississippi River Basin, USA. Journal of Hydrology,499:82-90.
8. Tran, Liem T., and Robert O'Neill,2013, Hierarchy and Cross-Scale Hydrologic Modeling, "in" Annual Meeting of Association of American Geographers, Los Angles, CA., pp.236-243.
9. Tran,Vi,and Liem Tran,2013,Geospatial Regression Models for Regional and Sub-Regional Mean Annual Streamflow, "in" Annual Meeting of Association of American Geographers, Los Angles, CA., pp.244-251.
10. O'Neill, Robert and Liem Tran,2013,Cross-Scale Hydrologic Modeling for Annual Sediment Load, "in" Annual Meeting of Association of American Geographers, Los Angles, CA., pp. 252-261.

Below is the final report for the EPA Interagency Agreement IA 95796201-0. Expected outcomes for the two years stated in the proposal include:

- At the end of the first year:
    - An annual load and flux model for total nitrogen*
    - Uncertainty analysis of the annual total nitrogen model*
    - An annual load and flux model for total phosphorous*
    - Uncertainty analysis of the annual total phosphorous model*
- At the end of the second year:
    - An annual load and flux model for sediment*
    - Uncertainty analysis of the annual sediment model*
    - A seasonal load and flux model for total nitrogen**
    - Uncertainty analysis of the seasonal total nitrogen model**

Tasks which are marked with (*) were complete. Tasks marked with (**) are not finished but kept going on with funding from other sources. In that context, we very much accomplished the tasks planned for the two years of the project.

In term of a tangible product, we have published two papers as follows:

Liem T. Tran, Robert V. O'Neill, Elizabeth R. Smith, Randall J.F. Bruins, Carol Harden (2013). Application of Hierarchy Theory to Cross-Scale Hydrologic Modeling of Nutrient Loads. *Water Resources Management*, 1:1-17

Liem T. Tran, Robert V. O'Neill (2013). Detecting the Effects of Land Use/Land Cover on Mean Annual Streamflow in the Upper Mississippi River Basin, USA. *Journal of Hydrology* 499:82–90.

A third manuscript has been submitted to *Applied Geography*. Its status is under the second review:

Liem T. Tran, Robert V. O'Neill, Randall J.F. Bruins Elizabeth R. Smith. Geospatial Regression Models for Mean Annual Streamflow in the Upper Mississippi River Basin, USA. *Progress in Physical Geography.* Accepted pending revision.

We organized a session entitled “Cross-Scale hydrologic Modeling: Challenges and Progress” at the Association of American Geographers (AAG) 2013 Annual Meeting, April 9-13, 2013, Los Angeles, California. We had three papers related to this project present in this session.

- Hierarchy Theory and Cross-Scale Hydrologic Modeling, by Liem Tran, Robert O’Neill.
- Geospatial Regression Models for Regional and Sub-Regional Mean Annual Streamflow, by Vi Tran, Liem Tran.
- Cross-Scale Hydrologic Modeling for Annual Sediment Load, by Robert O’Neill, Liem Tran

In addition, one MS student has been writing her thesis from her work in the project. More important, we are able to link the project to another on-going project to continue the RHYME2 project and to disseminate its results and web-based GIS applications (websites: http://160.36.51.185:8081/DataView/DataView.html and http://160.36.51.185:8081/DataInventory/dataDefault.aspx).

In general, given the limited resource, the project team did try their best to accomplish the proposed plan as much as possible. Furthermore, we closely followed the project’s QAPP. We are more than happy to answer any question you might have about this report and the project.

Determining Channel Protection Flows in Urban Watersheds Through Effective Strategies for Stormwater Management and Stream Restoration

Basic Information

Title:	Determining Channel Protection Flows in Urban Watersheds Through Effective Strategies for Stormwater Management and Stream Restoration
Project Number:	2012TN92B
Start Date:	3/1/2012
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	Second
Research Category:	Water Quality
Focus Category:	Ecology, Surface Water, Sediments
Descriptors:	Channel Protection; Stormwater Management; Stream Restoration; Bank Erosion; TMDLs; Urbanization
Principal Investigators:	John S. Schwartz, John S. Schwartz

Publications

There are no publications.

Methods, Procedures, and Facilities:

Task 1 - Pilot Site Sampling and Setup:

Rainfall and flow monitoring equipment will be set up at each pilot. Composite samplers to capture water samples at different stages will be installed to evaluate suspended sediment. Continuous stage and weather data will be monitored at each site. Automated composite samplers with flow measurement sensors will be purchased with USGS grant. Field surveys will be performed on the channel and floodplain of each pilot stream. The initial survey will be used to describe the baseline geometry of the stream and prepare inputs to the hydrologic and channel erosion models. Erosion pins will be installed on the banks of three cross-sections at each site. Pins will be measured every six months and following rainfall events greater than 1.0 inches. Additionally, Rapid Geomorphic Assessment (RGA) and modified Wolman pebble count will be conducted at each site (Simon and Klimetz, 2008). Detailed soil and vegetation characterization will be performed at each pilot site. Soils at each of these pilot streams will be characterized from in-situ shear strength testing using a submerged jet device to measure in-situ critical shear and erosion rates for cohesive material.

Progress to Date: Composite samplers have been purchased, and set up at multiple locations. Model sites have also been set up with turbidity sondes, stage probes, and rain gauges. Laboratory analysis will be performed to provide a relationship between WQ samples from the composite samplers and in-situ sondes. Additional efforts for model calibration will include topographic surveys (completed), characterizing bedload particle distribution, measuring critical shear in-situ, and characterization of vegetated properties at the reach scale.

It has been determined that erosion pins would be cumbersome and offer limited information towards the research goals within the time scales of the funded project. In lieu of erosion pins, historical cross-sections have been implemented at two research sites for analysis and comparison in futures studies.

It should be noted that the collected field data in this task support the modeling effort in Task 3.

Task 2 - Pilot Model Creation:

The project team will create detailed hydrologic/hydraulic and erosion models for each pilot stream so that model output can be incorporated into the SUSTAIN model. The model software will be public domain, approved by the EPA, and accepted by the professional community. For example, the hydrologic/hydraulic model recommended is EPA SWMM (EPA, 2008) or the Hydrological Simulation Program- Fortran (HSPF) model, and the geotechnical bank failure models will be USDA's Dynamic BSTEM. We will assume at this time that SWMM will be used. These models will be used in later tasks to evaluate the channel erosion, baseflow and WQ impacts of alternative stream protection options. The SWMM models includes rainfall, runoff, infiltration, evaporation, groundwater, hydraulic and baseflow components. Each model will be run to determine flow rates over the length of each pilot stream. Bank Stability and Toe Erosion Model (BSTEM) spreadsheets will be set up for continuous simulation to evaluate bank stability and toe erosion on each of the pilot streams. Dynamic BSTEM is a public-domain model developed by the USDA National Sedimentation Laboratory (USDA, 2009). Flow rates from the SWMM models will be introduced to the dynamic BSTEM spreadsheets at the appropriate locations. Soil and survey data will be used to describe the bed and bank materials and channel geometry in the model.

Progress to Date: Paul Simmons, a MS graduate student on the project has calibrated multiple BSTEM models and correlated those to spatial heterogeneity on the banks and critical shear estimates using the mini-jet tester (modified version of the original USDA submerged jet tester). Paul completed his master's thesis titled "*A spatial analysis of streambank heterogeneity and its contribution to bank stability*" spring 2014 semester (University of Tennessee, Knoxville, May 2014). Paul is currently working towards modifying his thesis into *Geomorphology*, a peer reviewed publication.

Robert Woockman, a PhD graduate student is in training learning the use of the EPA SWMM and USDA CONCEPTS models. At this point in the project it has been determined that CONCEPTS will provide a better analysis of in-channel processes when compared to Dynamic BSTEM as it includes fluvial and mass failure processes. The intention is to couple these models to provide an understanding of how different mitigation strategies will impact suspended sediment flux and channel modification. Coupling of models offers an understanding of the interaction of hillslope SMCs and in-channel restoration projects. This effort is time intensive but extremely important to gaining an understanding of influence of form and processes at the watershed scale on mitigation success. This has led to minimal effort towards the development SUSTAIN models at this point in the research project.

Initially there were intentions to work with Dr. Bill Lucas with respect to the research Robert Woockman was working on for his dissertation. However, travel logistics has made this option unreasonable and the decision was made to calibrate our own SWMM models representing catchments in Ecoregion 67. We have contacted David Hagerman with the City of Knoxville, Stormwater Engineering Department and we will be able to coordinate with their SWMM modeling on Second Creek.

Task 3 - Pilot Model Calibration:

The SWMM models will be run with the recent rainfall data collected by the nearby rain gauge. Relatively uncertain watershed characteristics of the model will be calibrated so that flow results match recorded flows as closely as possible. This calibration will reduce uncertainty and increase the reliability of the modelled flows. Flow results from these models will be entered into the BSTEM spreadsheets to drive the channel erosion analysis. Erosion results will be compared to those gathered by the yearly field surveys. The soils parameters of the BSTEM model will then be calibrated to match the observed measurements as closely as possible. This approach was similarly used by Simon and Klimetz (2008). The calibrated SWMM and BSTEM models can then be used to test any number of stream protection options or land use changes for their effect on long term stream health.

Progress to Date: See above statement in Task 2.

Task 4 - Shear Strength Guidance Creation:

The soils data calibrated in BSTEM will then be analyzed to determine which field-measured parameters (such as Torvane tester values, root density, etc.) are accurate predictors of shear strength. Relationships between the key parameters and shear strength will be determined. The project team will publish a simplified method for determination of bank and bed shear strength.

Proper use of inexpensive Torvane shear strength testers will be combined with field observations to determine a valid shear strength.

Progress to Date: There has been modification to this objective over the previous year. Only recently a great deal of research has been published or is in review regarding the spatial discontinuity of critical shear stress values with relation to soil parameters, root density, and temporal seasonal patterns. In light of this Paul Simmons MS research was restructured to provide a survey based method to determine channel resistance with respect to critical shear values and spatial heterogeneity of hard points on the banks. Simmons's research focused on using the mini jet tester device to characterize critical shear and relating these values through a geostatistical approach to channel resistance properties. Channel stability was determined through the use of BSTEM and incorporated vegetation estimates and critical shear at each site. The title of his completed thesis is noted in Task 2 above.

Task 5 - Evaluation of Potential Channel Erosion for Pilot Streams:

The SWMM models for the reference streams will be altered by changing the land uses to residential and commercial and applying the long-term rainfall record. The increased flow hydrographs determined from SWMM will be fed into BSTEM until the channel geometry stabilizes for each stream. The progression of channel geometries will be compared to the geometries of the newly and historically urbanized pilot streams. The BSTEM models may be further calibrated based on this comparison, which will provide insight into the evolution of urban stream degradation. Several similar model runs will be performed after varying the stream channel characteristics in BSTEM for each pilot stream. The effects of several critical factors such as channel shear strength, bank angle and vegetation on sediment load will be determined. The total erosion load potential will then be tabulated for a range of stream and watershed conditions.

Progress to Date: The only modification to this objective is CONCEPTS has been chosen as the preferred model to capture in-channel processes. For additional details see above statement in Task 2.

Task 6 - Relationship between RGA Score and Erosion Potential:

The Rapid Geomorphic Assessment (RGA) technique developed by the USDA National Sedimentation Laboratory will be used to score each of the pilot stream reaches. The RGA provides an overall rating for the susceptibility of a channel to erosion. Erosion loads for the pilot streams will then be tabulated based on RGA score and hydrologic area to determine the relationship between these factors. This task is key in developing simplified field protocols that MS4s can implement, and optimally target restoration projects for channel protection. This RGA datasheet can be designed for easy incorporation into existing stream assessment protocols such as the "Maryland Protocol" (Yetman, 2001) that are currently being used across the country by MS4 staff.

Progress to Date: See above statement in Task 1.

Long-term Evaluation of Norris Dam Operation under Changing Environments

Basic Information

Title:	Long-term Evaluation of Norris Dam Operation under Changing Environments
Project Number:	2013TN100B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	2nd Tennessee
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Management and Planning, Surface Water
Descriptors:	Climate Change, Water Resources Management, Reservoir Operation, Hydrology, Optimization, Flood, Drought
Principal Investigators:	Ungtae Kim

Publications

1. Rungee, J., U. Kim, J. Schwartz, C. Cox, and J. Hathaway,2014, Long-Term Evaluation of Norris Dam Operation Under Climate Change,in" Proceeding of Third Annual Watershed Symposium, Tennessee Water Resources Research Center, University of Tennessee, Knoxville, TN., pp. 38-41.
2. Runge, J.,2014,Long-Term Evaluation of Norris Reservoir Operation under Climate Change, MS Thesis, Department of Civil and Environmental Engineering, The University of Tennessee, Knoxville, TN. pp.174.

Title:
Long-term evaluation of Norris Dam operation under changing environments

Problem and Research Objective

The Tennessee Valley Authority (TVA) is a well-known, successful example of comprehensive river basin development and water resources management. In May 2004, TVA approved a new policy for TVA reservoir systems that shifts the focus from achieving specific summer water elevation in TVA-managed reservoirs to managing the flow of water through the river system. This new policy specifies flow requirements for both individual reservoirs and the entire system. TVA as of 2010 owns and operates 29 hydropower plants. The Norris reservoir has the largest flood control capacity in the eastern portion of the TVA region. Therefore, the downstream regions of Norris will be highly subject to the flow released from the Norris reservoir.

It has been reported that the percent change in water use in the Tennessee River Watershed from 2005 to 2030 is projected as +10, +32, and +65% for industry, pubic-supply, and irrigation. Considering that the Norris reservoir was built in 1930s, it is the right time to evaluate its long-term performance in controlling flows and water levels during drought and flood seasons under changing watershed conditions. These should include sediment impoundment, increasing water demand and varying patterns, and more extreme hydrologic events that may be caused by climate change, which is highly expected in next 50 years.

This project aims to provide practical decision-making information for long-term water resources management in the TVA region based on the demonstrated data sources and robust hydrologic methods. The uncertainty of the results generated in this project inherently relies on the credibility of current and future watershed information. This project therefore will emphasize the role of the operating guide currently used in the Norris reservoir to maintain the Clinch River keeping its designated performance. Main objectives are summarized as follows.

A. Suggest the future variability of inflow, outflow, and water level of the Norris reservoir based on future climate projections and changing hydrologic conditions.
B. Evaluate the reliability for water supply, environmental requirements, navigation, and hydropower generation of the Norris reservoir under the future drought conditions caused by climate change and increasing water demands.
C. Evaluate the performance of flood control by the Norris reservoir under future flood conditions caused by climate change.

Methods, Procedures and Results

Extensive hydrologic analysis and climate simulation outcomes are required to evaluate the long-term operation of the Norris reservoir under future climate change. Figure 1 describes the schematic of analysis. To represent future climate change, the Community Earth System Model 1.0 (CESM1.0), a general circulation model (GCM) accessible through the Intergovernmental Panel on Climate Change's (IPCC's) Coupled Model Intercomparison Project Phase 5 (CMIP5), with the Representative Concentration Pathway 4.5 (RCP4.5) was used to obtain projected precipitation and temperature data for three future climate scenarios, 2030's, 2050's, and 2070's. Three hydrologic models (multiple linear regression model (MLR), two layer soil moisture accounting model (TANK), and artificial neural networks model (ANN)) were individually calibrated on 30 years of observed runoff data and combined utilizing linear programming to consider the strengths of each model. Inflow hydrographs were simulated for the future time spans using projected precipitation and temperature. Reservoir routing was then simulated using the inflow hydrographs via mass balance and the current operation policy to determine the storage elevation of the reservoir. Next, the routing simulations were utilized as input for a genetic algorithm forced optimization model, to minimize an elevation-based penalty value, optimizing Norris Reservoir's operation policy. Finally, the operation performance of Norris Reservoir's current operation policy versus the policies generated by the developed optimization model for each projected scenario were evaluated.

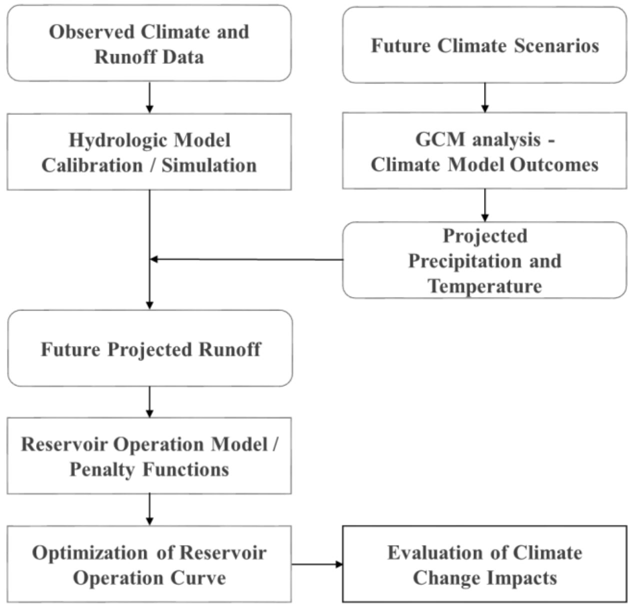

Figure 1. Schematic of research approach

Principle Findings and Significances

Major findings can be summarized in three parts; future climate change, hydrologic modeling, and reservoir operation.

A. Future climate change

Based on GCM analysis under a medium level of emissions scenario, it was noticed that the most significant variances in temperature laid in the winter months for all three GCM time spans, which showed an average annual change from the observed dataset of -0.42°C, 0.34°C, and 0.89°C for the time spans 2030's, 2050's, and 2070's, respectively. The changes of precipitation from the current climate condition showed 14.0, 18.27, and 19.9 % for the time spans 2030's, 2050's, and 2070s, respectively. Overall, warmer and wet annual climate condition is expected.

B. Hydrologic modeling

Table 1 summarizes the strength of individual hydrologic model and combined model. From Table 1, it can be seen that the MLR model more strongly predicted the annual runoff and low runoff events. The tank model's strength laid in predicting the low runoff season and high runoff events. Finally, the ANN model performed best at predicting overall seasonality (total error), high runoff season, and runoff in between the 25th and 75th quartiles of the distribution. The combined model was composed through linear programing coupling the three individual models with the objective function to yield the lowest prediction error (i.e., superior model performance than individual models), and the observed data utilizing the entire timespan. The combined model produced an R^2 of 0.80, and adequately accounted for seasonality and extreme runoff. Coupling with future climate change data, the changes in annual runoff for the 2030's, 2050's and 2070's were projected as 20.71, 23.78, and 24.33 %, respectively.

C. Reservoir operation

Penalty values for reservoir operation were averaged through 100 Monte Carlo realizations. Performance of the optimization model was determined by comparing three scenarios, which are performance using 1) the current operation policy guide lines (Current), 2) the optimal operation policy determined from BASE (BASE_Opt), and 3) the optimized operation policy determined with respect to each future scenario (TS_Opt). A summary of the optimization and individualized penalty results are given in Table 2. BASE_Opt and TS_Opt policies both showed large decreases in penalties compared to the current policy (Table 5). The BASE_Opt scenario showed penalty decreases ranging from 22.2 to 24.4 %, while the TS_Opt scenario showed the decrease of penalty up to 37.0 %.

Although the current policy was able to handle the higher inflow, the generated penalties were greatly decreased through the use of a genetic algorithm driven optimization model. The results could be attributed to the increased inflow for Norris Reservoir, enabling the maintenance of reservoir elevation at the flood guide line to be more easily accomplished; although, this increased the risk for flooding downstream.

Table 1. Comparison of hydrologic models

Test	Equation	MLR	TANK	ANN	Combined Model
R^2 (Overall Prediction)	$= 1 - \sum_i \frac{(OBS_i - Modelled_i)^2}{(OBS_i - \overline{OBS})^2}$	0.77	0.73	0.81	0.80
Total Error (mm) (ABS Error)	$= \sum \lvert OBS_t - Model_t \rvert$	4545	5082	4093	4131
Annual Runoff Error (mm) (Full 30 yr Time Span)	$= \lvert OBS_{annual} - Model_{annual} \rvert$	19.49	37.16	28.54	17.68
High Runoff Season Error (Dec - May)	$= \sum_{Dec}^{May} \left\lvert \frac{OBS_t - Model_t}{OBS_t} \right\rvert$	1.17	1.09	0.93	0.99
Low Runoff Season Error (Jun - Nov)	$= \sum_{Jun}^{Nov} \left\lvert \frac{OBS_t - Model_t}{OBS_t} \right\rvert$	4.10	3.76	4.11	4.07
Low Runoff ABS Error (mm) (< 10% OBS Distribution)	$= \sum \lvert OBS_t - Model_t \rvert_{OBS<10\%}$	170	203	208	156
High Runoff ABS Error (mm) (> 90% OBS Distribution)	$= \sum \lvert OBS_t - Model_t \rvert_{OBS>90\%}$	1330	1044	1057	1142
25-75 Quartile ABS Error (mm) (50% OBS Distribution)	$= \sum \lvert OBS_t - Model_t \rvert_{25\%<OBS<75\%}$	1928	2574	1655	1734

Table 2. Reservoir operation results

year	ΔPenalty from Current to BASE_Opt (%)	ΔPenalty from Current to TS_Opt (%)
BASE	-22.4	-22.4
2030	-23.3	-35.4
2050	-22.2	-34.6
2070	-24.4	-37.0

In conclusion, for a reservoir that works within a network, an increase of runoff in the entire system may pose many threats unexplored by this study. Therefore, it is recommended that future studies consider encompassing the entire TVA system, and that temporal resolution be increased to a daily time-step, instead of monthly, to account for extreme events. This will allow the ability to work more closely with TVA, helping to better define the penalty function, more accurately account for the reservoir network process, and compare the combined hydrologic model with the TVA SAC-SMA model. Moreover, the results produced could also be attributed to the GCM used. Due to the uncertainty and variance from one GCM to the next, it is recommended that a wide variety of GCMs, and RCPs scenarios, be taken into consideration.

This project provided a good opportunity to train a graduate student for watershed management based extensive analysis of hydrology and climate change in a large scale. This project especially contributed to bridging theoretical hydrologic analysis in laboratory and real world watershed management (e.g., TVA). A graduate student and the PI directly communicated with TVA hydrologists to discuss many technical details to build a reservoir operation model and penalty functions. As a result, one master's thesis and one technical presentation were completed and one journal paper is being prepared through this project.

Chemical and Morphological Analyses of Trout Otoliths as a Measure of Aluminum Exposure in Streams Impacted by Acid Deposition in the Great Smoky Mountains National Park

Basic Information

Title:	Chemical and Morphological Analyses of Trout Otoliths as a Measure of Aluminum Exposure in Streams Impacted by Acid Deposition in the Great Smoky Mountains National Park
Project Number:	2013TN101B
Start Date:	3/1/2013
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	2nd Tennessee
Research Category:	Biological Sciences
Focus Category:	Acid Deposition, Ecology, Water Quantity
Descriptors:	Acid Deposition, Stream, Trout, Otoliths, Baseflow, Stormflow, Aluminum
Principal Investigators:	Michelle Connolly, John S. Schwartz

Publication

1. Connolly, M.H., K.J. Neff, M.A. Kulp, J.S. Schwartz, S.E. Moore,and T.B. Henry,2013, Chemical Analysis of Trout Otoliths as a Measure of Age-Dependent Deposition of Aqueous Aluminum in an Appalachian Stream, Great Smoky Mountains Conservation Association Annuli Report, Knoxville, TN. pp.87-102.

Problem and Research Objectives:

Acid deposition is a global issue, which greatly affects fish populations throughout the Northern Hemisphere. In the Southeastern United States stream acidification is thought to be responsible for the extirpation of brook trout (*Salvelinus fontinalis*) from many headwater streams in the Great Smoky Mountains National Park (GRSM). The management of fishery resources and particularly populations of native brook trout is a high priority for conservation efforts within the Park. Streams within the Great Smoky Mountains National Park are particularly susceptible to the effects of acid deposition due to the low buffering capacity associated with the geology in this region.

The chemical analysis of fish otoliths (ear bones) represents a unique opportunity to decipher the complex relationship between water chemistry and aluminum as they pertain to biologically-relevant environmental exposure. Otoliths have long been used as an environmental archive as they continuously incorporate inorganic material (including trace metals) into their calcified matrix. Yet, relatively little is known about Al uptake in freshwater fish, especially among streams impacted by acid deposition. Therefore, gaining a better understanding of how fish respond to acidic deposition and associated release of trace metals across the Park will contribute GRSM monitoring programs as well as the selection of suitable stocking sites within extirpated streams and waterways.

In a previous study, we found that rainbow trout living at higher elevations (3820 ft) of Walker Camp Prong were buffered from exposure to trace metals by high calcium levels, due in part to the use of a dolomite aggregate on the upper reaches of route 441. In the current study we extended our research efforts to four other GRSM streams that are not buffered by anthropogenic calcium input, in order to determine whether the age-specific Al/Ca trends observed among fish from Walker Camp Prong are applicable to other regions and species (brook trout) in the Park.

The objectives of this study were to assess otolith Al/Ca ratios among trout living in four GRSM watersheds (Table 1) in order to

1) Further substantiate our preliminary findings of age-dependent Al deposition in the Park;

2) Determine whether there is species-specific uptake of aqueous aluminum in GRSM streams.

3) Determine whether aqueous aluminum exposure has influenced fitness indices in GRSM trout.

4) Determine the extent of abnormal otolith bone formation across elevation

Methods, Procedures and Results:

Four watersheds (Rock Creek, Cosby Creek, Oconaluftee River, Cataloochee River) were selected largely on the availability of archival water chemistry data. We selected 2-3 sites within each watershed that encompassed a range in pH, aluminum, and calcium. Notably, all four watersheds have much lower calcium levels than Walker Camp Prong, and thus may not be nearly as buffered from aqueous Al.

Table 1. Sites identified for collection of fish samples for analysis of otolith aluminum concentration. Stream chemistry parameters [mean aqueous pH, aluminum (Al) and calcium (Ca)] among archival datasets (N= 30) are also shown.

Stream	*Site #*	*Elevation (ft)*	*Species*	*# fish*	*Mean pH*	*Al (ppm)*	*Ca (meq/L)*	*Al/Ca (uM/L)*
Rock Creek	4	2076	BT	20-25	5.83	0.05	50.80	0.0769
Rock Creek	137	2782	BT	20-25	5.84	0.06	56.65	0.0795
Cosby Creek	492	2732	BT	20-25	6.35	0.04	68.84	0.0388
Cosby Creek	114	2519	RT/BT	20-25	6.39	0.03	67.88	0.0301
Cosby Creek	1A (new)	1960	RT/BT	20-25	n/a	n/a	n/a	n/a
Oconaluftee	251	4005	BT	20-25	6.26	0.04	123.64	0.0209
Oconaluftee	270	2798	RT	20-25	6.50	0.02	43.29	0.0343
Oconaluftee	268	2185	RT	20-25	6.58	0.03	50.15	0.0370
Cataloochee	147	2461	RT	20-25	6.78	0.02	52.84	0.0353
Cataloochee	148	2474	RT	20-25	6.96	0.03	65.73	0.0297
Cataloochee	149	2549	RT	20-25	6.78	0.03	50.26	0.0510
Walker Camp Prong	30	1462	RT	22 (2011 survey)	6.63	0.04	107.60	0.0277
Walker Camp Prong	66	2680	RT	24 (2011 survey)	6.48	0.04	102.33	0.0290
Walker Camp Prong	73	3360	RT	22 (2011 survey)	6.48	0.05	102.92	0.0362
Walker Camp Prong	74	3820	RT	23 (2011 survey)	6.80	0.05	157.78	0.0267

Field sites and sample collection

Last summer we set out to expand upon work that we began two years ago, namely to measure trace metal uptake in fish bones in order to decipher long-term stream chemistry trends in the Great Smoky Mountains National Park (GRSM). In June-August 2013, we sampled a total of 345 fish from 11 sites across 4 streams in the GRSM as outlined in Table 2. Whenever possible, both rainbow trout and brook trout were collected from the same site; otherwise 25-30 of either species were sampled for subsequent trace metal analysis.

Water samples were also collected from each site to determine whether site-specific chemistry was within normal range on the day the fish were sampled (see Table 2). Standard EPA methods were used to measure pH, conductivity and acid neutralizing capacity (ANC) as described by Neff et al. (2009), while trace metals (Al, Ca) were measured via ICP-AES as described below.

Fish were weighed (g) and measured (mm), then stored on ice until further analyses. Paired sagittal otoliths were removed through the gills as described by Secor et al. (1992), rinsed in ultrapure 0.45um-filtered distilled water, placed in EPA glass vials, dried for two days in a 65 °C oven and weighed to the nearest 0.1 mg. Fish were aged by counting otolith growth rings from one or both otoliths under light microscopy. Paired otoliths were examined using a Zeiss Stemi SV11 stereomicroscope and imaged with an Axiocam HRc Camera.

Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)

Trace aluminum (Al) and calcium (Ca) levels were quantified using standard ICP-AES methods (Neff et al. 2009). Otoliths were solubilized in 1 ml of trace metal grade nitric acid (Fisher Scientific) and placed on a shaker for 1-2 days. Samples were subsequently diluted to a final concentration of 2% nitric acid in acid-washed plastic HPDE vials. Diluted samples were standardized to trace metal standards (2.5, 5, 50 and 100ppm) and analyzed using an IRIS Intrepid II XS inductively coupled plasma-atomic emission spectrometer. To ensure quality control, otoliths samples were run alongside a 2% nitric acid blank as well as a spiked blank, which contained a known concentration (2.5 ppm) of Al and Ca standards. Recovery rates were 99.11% ± 0.0176 for Al and 91.51% ± 0.0068 for Ca.

Preliminary data indicate that the aluminum signature among brook trout and rainbow trout otoliths are similar and do not significantly increase with age, suggesting that rainbow trout could be used to determine life-long Al exposure where both species co-exist. However, the aluminum to calcium ratios (Al:Ca; Fig 1) significantly differed between species (ANOVA, $p < 0.0001$), likely due to the differential growth rates (and consequently, otoliths size) exhibited by these two species.

Therefore, species-specific regression analyses will be necessary in order to make predictions about stream conditions, especially where long term data are not available. Fish collected in Cosby Creek, Rock Creek, Cataloochee and Oconaluftee River (Table 2) will contribute toward the developmental of these regressions.

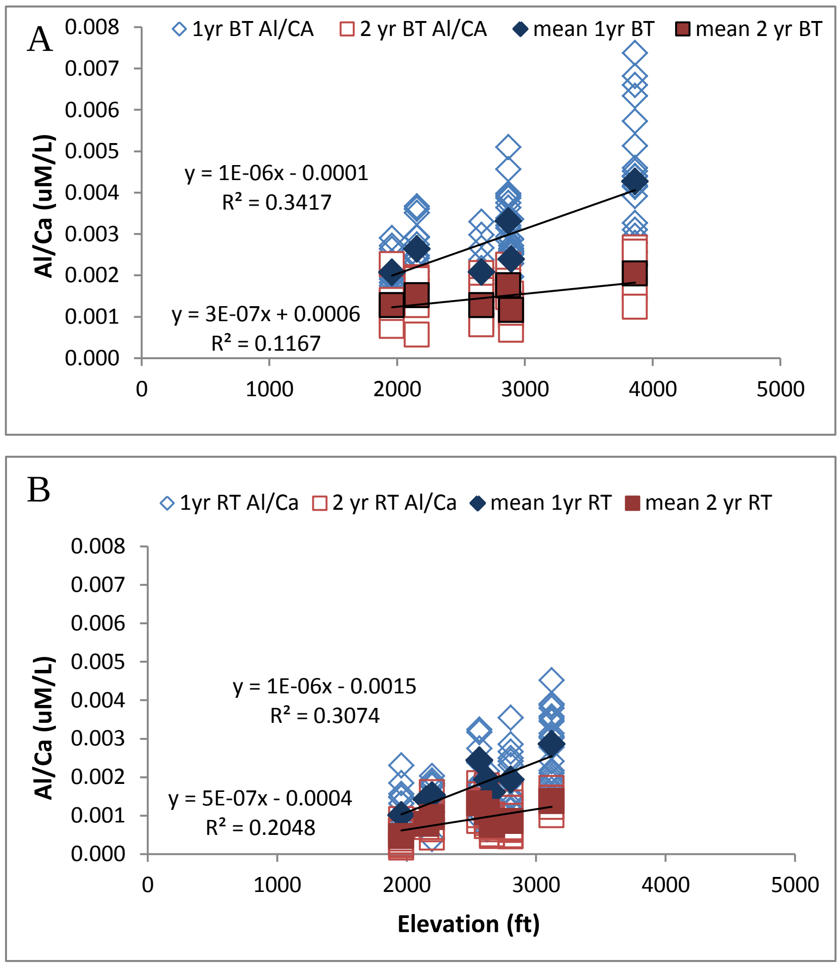

Fig. 1. Age-specific Al/Ca trends among brook trout (BT;A) and rainbow trout (RT; B) living across elevation in the GRSM

A detailed analysis is currently underway to determine how these observations relate to archival water chemistry data across 4 streams (11 sites) in the Park. Abnormal (vateritic) bone formation has also been detected among both species. Morphological analysis of BT and RT otoliths is currently underway (based on images that were taken prior to their chemical analysis) to determine the extent of abnormal otoliths bone formation across elevation.

Table 2. Water chemistry (pH, conductivity and acid neutralizing capacity) and trace metal analysis of grab samples collected on the days rainbow trout (RT) and brook trout (BT) were sampled are shown.

Site	Date	Conditions	# Fish	pH	Conductivity	ANC	Al (ppm)	Ca (ppm)	Mg (ppm)
Cosby Creek, site 1A (below confluence w/ RC)	06/05/2013	Baseflow	25 BT, 25 RT	6.74	14.42	49.52	0.0258	1.2132	0.3469
Cosby Creek, site 114	06/04/2013	Stormflow	25 BT, 25 RT	6.46	15.84	40.03	0.0225	1.2826	0.4181
Cosby Creek, site 492	06/04/2013	Stormflow	25 BT	6.47	15.67	188.98	0.0185	1.3127	0.4106
Rock Creek, site 3/4	06/11/2013	Stormflow	26 BT, 6 RT	5.76	12.26	2.91	0.0673	0.9196	0.2495
Rock Creek, site 137	06/05/2013	Baseflow	26 BT	5.97	13.29	5.96	0.0533	0.9898	0.2741
Cataloochee, site 148	06/25/2013	Baseflow	26 RT	7.13	16.39	125.64	BDL	1.2221	0.5661
Cataloochee, site 147	06/25/2013	Baseflow	25 RT	6.96	14.13	72.43	BDL	0.9707	0.3017
Cataloochee, site 493	06/25/2013	Baseflow	30 RT	6.80	11.03	54.63	0.0236	0.7248	0.2069
Oconaluftee, site 268	08/15/2013	Stormflow	28 RT	6.53	13.74	60.00	0.0212	0.9422	0.3141
Oconaluftee, site 270/BEF-0	08/15/2013	Stormflow	27 RT	6.43	11.89	52.60	0.0216	0.8130	0.2492
Oconaluftee, site 251/BEF-2	08/15/2013	Stormflow	26 BT	6.19	23.30	27.80	BDL	1.8407	0.6317

Training

Our field crew consisted of undergraduate volunteers and GRSM interns. An undergraduate student also helped with fish dissection and sample collection in the lab. In addition, Dr. Connolly helped train a new graduate student to use the Inductively Coupled Plasma-Atomic Emission Spectrometor (ICP-AES), which will be used for ongoing GRSM water chemistry analyses.

References

Neff KJ, Schwartz JS, Henry TB, Robinson RB, Moore SE, Kulp MA (2009) Physiological Stress in Native Southern Brook Trout During Episodic Stream Acidification in the Great Smoky Mountains National Park. Arch Environ Contam Toxicol 57(2):366-376 doi:10.1007/s00244-008-9269-4

Secor DH, Dean JM, Laban EH (1992) Otolith removal and preparation for microstructural examination In: Stevenson, DK, Campana SE (eds) Otolith microstructure examination and analysis. Can. Spec.Publ. Fish. Aquat. Sci. 117: 19-27.

Re-filling the Bucket: Recharge Processes for the Memphis Aquifer in the Exposure Belt in Western Tennessee

Basic Information

Title:	Re-filling the Bucket: Recharge Processes for the Memphis Aquifer in the Exposure Belt in Western Tennessee
Project Number:	2013TN102B
Start Date:	3/1/2013
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	7th Tennessee
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Groundwater, Management and Planning
Descriptors:	Recharge, Hillslope Hydrology, Ground Water, Vadose Zone, Monitoring
Principal Investigators:	Brian Waldron, Daniel Larsen

Publications

There are no publications.

Introduction

Little is currently known regarding direct recharge to the Memphis aquifer across the unconfined region in western Tennessee; however, initial investigations indicate that little recharge may penetrate through the upland surfaces, taking possibly 100 years to move from the ground surface down to the water table. Observation of seasonal rise and fall in the water table in these areas requires operation of a more responsive recharge mechanism. Gaining an understanding of recharge processes in the unconfined region of the aquifer is critical to understanding input rates both spatially and temporally so as to ascertain the impact of land use and climate change and ultimately effect the long-term sustainability of this valuable and heavily relied upon natural resource. This project investigates recharge processes in the unconfined region of the Memphis aquifer at the Pinecrest research site, near LaGrange, Tennessee. Initial investigations have included using vadose-zone and saturated zone chloride mass balance methods (CMB) to estimate recharge in the upland region (i.e. thick vadose zone), installation of and continuous water level monitoring in two observation wells on an upland surface screened within the Memphis aquifer, and recurrent analyses of vadose zone soil moisture profiles within one of the wells using a neutron probe. Furthermore, geologic mapping and reconnaissance soil studies have clarified geologic and soil control on recharge processes. Although prior investigations at the site indicated a slow (~100 yrs) migration of infiltrated water through the vadose zone in the upland region, it is hypothesized that seasonal recharge occurs along the hillslopes, gullies, and stream valleys. Testing this hypothesis will clarify which parts of the regional landscape are most significant for recharge and will greatly advancing our understanding of recharge to the Memphis aquifer and sustainability of its water resources.

Methods, Procedures, and Facilities:

Our activities to date have included installation of 4 lysimeter and tensiometer (LT) clusters, completion of a deep monitoring well in the Memphis aquifer in the valley floor adjacent to the LT clusters, a Parshall flume along an intermittent stream adjacent to the LT clusters and a shallow monitoring well in the Memphis aquifer downgradient of the wells and LT cluster (Fig. 1).

The lysimeter and tensiometer clusters are located in four landscape positions along the hillslope: shoulder slope (SS), back slope (BS), back slope gully floor (GF), and toe slope in the valley floor (VF). Construction of the clusters was completed so as to parallel the hydrologic feature of interest (e.g., parallel to slope contours or parallel to stream channel or gully). The lysimeters and tensiometers were installed in boreholes approximately 0.5, 1.0 and 1.5 m deep. The boreholes were dug with a post-hole digger and bucket auger or by power auger. Samples were taken at 0.25 m increments and retained for sieve analysis. The base of lysimeter boreholes was filled with silica powder to facilitate suction of soil water into the lysimeter. After inserting the lysimeters and tensiometers, the boreholes were back-filled with natural soil material excavated from the site. The tensiometers were filled with water and a few drops of Jet-fill Blue solution to limit algae growth and facilitate determining the fill status of the tensiometers.

The deep monitoring well (valley floor (VFW) well in Fig. 1) was drilled and constructed during July, 2013 by Tri-state Testing Services. The borehole was drilled to 115 ft depth with 5 split spoon samples taken at 30, 48, 68, 83, and 96 feet. The upper 25 ft of the borehole penetrated silty sand and sand attributed to the alluvial valley fill. The interval penetrated from 25 to 115 ft was predominantly light brown to gray very fine to fine-grained micaceous sand with white clay intraclasts and thin (~ 1 cm thick) clay lamina. These strata are attributed to the Memphis Sand. A 4-inch diameter PVC well was completed in the Memphis Sand with the screen set from 102 to 112 ft. The shallow monitoring well was constructed as a drive point piezometer (DP) (Fig. 1) during September 2013. A borehole was excavated to 14 ft depth with a bucket auger. Samples were taken at 0.5 m intervals for sieve analysis. A stainless steel drive point piezometer was inserted in the borehole and pushed to a depth of 14 ft. The DP screen is 4 ft long and at a depth interval of 10 to 14 ft. The strata penetrated during the DP installation were all fine- to medium-grained micaceous sand and attributed to the lower alluvium and Memphis Sand.

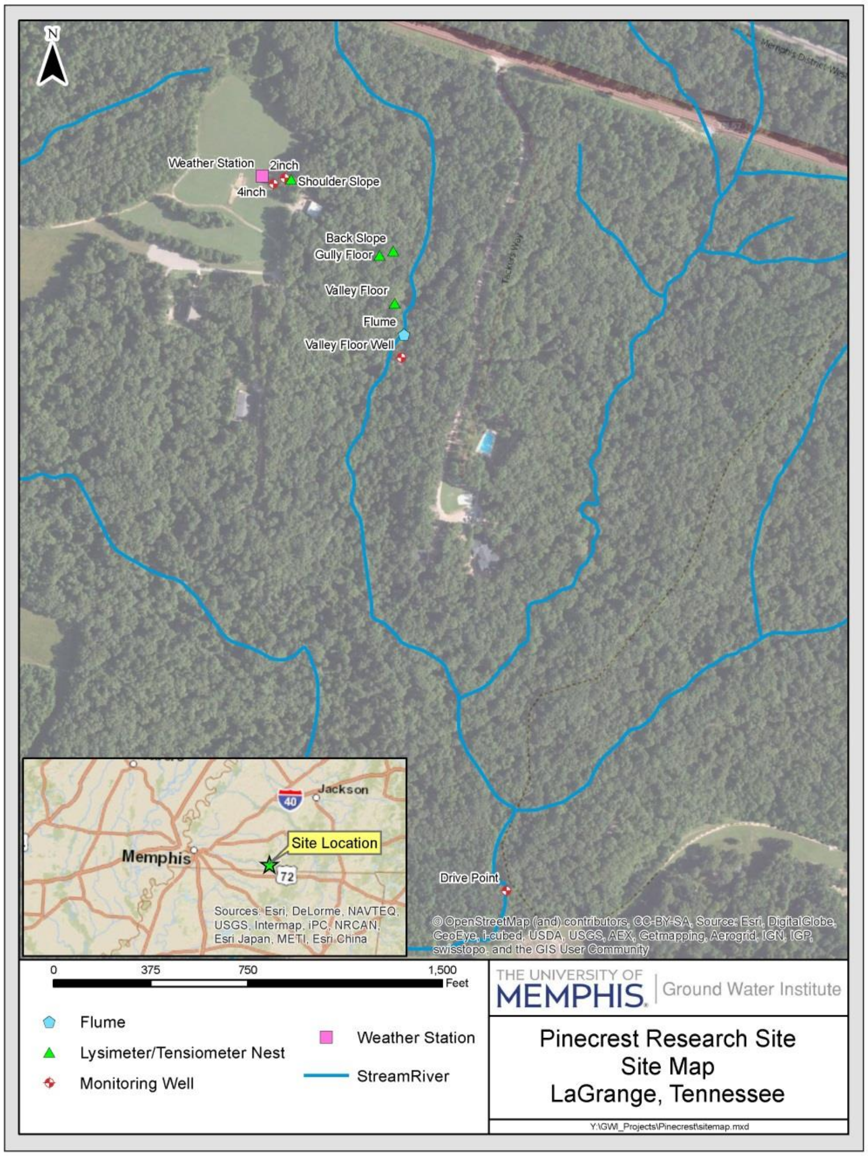

Fig. 1. Site map of Pinecrest research site. Relevant features discussed in the text are shown.

A small Parshall flume was installed in the intermittent stream valley near the VF LT cluster and the valley floor well (Fig. 1). A barrier was constructed upstream of the flume and the side of the flume were reinforced with sand bags. The flume is capable of measuring flows of approximately 1 ft depth or less.

Pressure transducers have been installed in 2-inch monitoring well at the shoulder slope location, the valley floor well, the Parshall flume, and the drive point well. A barometer pressure transducer is installed in the fully screened well at the shoulder slope location. Transducer data are collected on a monthly basis.

A weather station was installed at the hill top location (Fig. 1). The initial weather station provided inconsistent results; however, a new weather station was installed in February 2014 and is operating properly. A plastic rain gauge is attached to the weather station to collect samples of precipitation.

The Pinecrest site has been visited on a bi-weekly basis since late August for data and sample collection. At each visit, the tensiometer readings are made and the tensiometers are filled with solution as need to maintain proper operating conditions. The lysimeters are sampled by evacuating the volume of water using a hand pump. The total volume of water obtained is determined and a sample taken. The hand pump is then used to restore a vacuum of 60 centibars in the lysimeters. The rain gauge quantity is recorded and a sample taken. Water levels are taken in all available wells and transducer data is downloaded as needed. Weather station data are downloaded as needed.

The sediment samples from lysimeter, tensiometer and well installation were taken to Johnson Hall at the University of Memphis for sieve analysis. The samples were split until a mass of 30 to 50 grams was obtained. The sample was then mixed with 10% sodium pyrophosphate solution and agitated for at least two hours prior to wet sieving to remove the fine fraction (less than 63 microns). The coarse fraction was dried and sieved using standard methods. The resulting data were plotted for grain size distribution curves and uniformity coefficients determined.

Lysimeter, stream (when available), and rain water from the site are sampled for chemical analysis on a monthly basis. Field measurements are made for temperature, pH, dissolved oxygen, and conductivity. Water samples taken at the site are returned to the University of Memphis water lab for analysis of common anions and cations. The samples are filtered through 0.45 micron cellulose filters and analyzed on a Dionex DX120 ion chromatography unit within three days of sampling. Filtered samples are also used for alkalinity titration, which are completed in duplicate. The lysimeter samples have inordinately high sulfate contents that seem unreasonable for dilute waters in western Tennessee. We have investigated whether the silica powder packing material was releasing sulfate but those tests are negative. Lab tests of lysimeters installed in Pinecrest soils as well as a non-reactive medium were conducted to assess whether the sulfate arises from the soil materials or the lysimeters themselves. The lab results suggest that the sulfate originates in the Pinecrest soils and not from the installation or sampling procedures. The rain water samples have inordinately high acetate contents, likely due to degradation of the polyacetate plastic container.

Preliminary results

The soil and sediment analyses confirm field observations indicating that the surface sediment at the upland (SS) location is dominantly silt to 2 m depth. Both the BS and GF sites have surface soil with as much as 60% silt but are underlain by silty sand strata. The VF site has surface soil composed of sandy silt. Soil and sediment texture greatly influences the lysimeter and tensiometer data, with the sandier surface soils showing the greatest potential for infiltration and silty soils remaining saturated most of the year. Pressure transducer data from the wells indicate that the water levels are greatest in the DP piezometer with lower levels in the hill top and VFW wells. The gradient in water levels in the upland wells shows potential movement toward the upland valleys. Transducer data from the flume and DP show a consistent response to precipitation event, especially for rainfall events greater than 1 inches of accumulation. The hill top and VF well show little or no response to precipitation events.

Discussion

The initial sediment analysis and stratigraphic results confirm previous observation that the back slope is covered in a thin veneer of sandy silt overlying the Memphis Sand and that a substantial of silty sand valley fill alluvium is present in the intermittent stream valley. Detailed analysis of the data collected does not allow for quantitative assessment of recharge at present. Qualitatively, however, the shoulder slope LT cluster continually yields water from lysimeters, whereas few lysimeters from the other LT clusters consistently yield water. These results are consistent with the conceptual model in that soil water is not able to percolate through the upland soil zone, whereas infiltrating water at the hillslope and valley floor locations is either used by the vegetation or drains through to the underlying sand. The deep wells show little or no response to precipitation events, in contrast to the DP piezometer, which suggests that the saturated Memphis Sand is hydraulically separated from the near surface hydrology.

Training activities

This study has included effort from several students from the departments of Civil Engineering and Earth Sciences at the University of Memphis. Originally, the project was to be the dissertation topic for a Ph.D. student; however, the student discontinued effort on the project at the end of the summer 2013. Drs. Larsen and Waldron, and Ground Water Institute staff members Scott Schoefernacker and James Eason as well as student Adrianna Isbell performed the sampling and data recording during the fall 2013. Graduate student John Bursi took over the project in January 2014 and will use the data collected in his Master's thesis. As many as 8 students in the departments of Earth Sciences and Civil Engineering have been involved with various aspects of the project, including LT cluster construction, sampling, soil analysis, water-level measurements, and chemical analysis.

Engineered Strategy to Remediate Trace Organic Contaminants using Recirculating Packed-Bed Media Biofilters at Decentralized Wastewater Treatment Systems

Basic Information

Title:	Engineered Strategy to Remediate Trace Organic Contaminants using Recirculating Packed-Bed Media Biofilters at Decentralized Wastewater Treatment Systems
Project Number:	2013TN99B
Start Date:	3/1/2013
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	2nd Tennessee
Research Category:	Water Quality
Focus Category:	Acid Deposition, Non Point Pollution, Water Quality
Descriptors:	Trace Organic Contaminants, Decentralized Wastewater Treatment, Media Biofilters, Fixed-film
Principal Investigators:	John R. Buchanan, Jennifer DeBruyn

Publications

There are no publications.

Nature, Scope and Objectives

Packed-bed media biofilters are a slow-rate, fixed-film (or attached-growth) unit process used for secondary and tertiary treatment. This process passes effluent through a porous, inert media (the packed-bed) where waste constituents diffuse out of the bulk water and into the biofilms that form on the media. Aeration is provided as the wet media is exposed to atmospheric oxygen. A recirculating packed-bed media biofilter (RPBMP) recirculates the effluent through the media several times for enhanced organic carbon removal and nitrification (oxidation of ammonia to nitrate). After trickling through the media, effluent is divided between the recirculation tank (for additional passes through the media) and to final discharge (typically via a drip irrigation system). Because the influent from primary treatment is anaerobic, the recirculation tank is usually anaerobic and this reducing-environment allows for denitrification. Under reducing conditions, nitrate can be converted to nitrogen gas, thus reducing the nitrogen concentration in the effluent.

By design, the organic loading rate to RPBMBs is low (typically 2 to 5 kg BOD_5 100 m^{-2} d^{-1}). This loading rate minimizes the accumulation of biosolids within the media and starves the microorganisms for organic carbon rather than oxygen (endogenous respiration). It is possible that this operating mode may encourage the aerobic biodegradation of otherwise recalcitrant trace organic waste compounds (TOWC). Further, there is some evidence that changing from oxidizing to reducing conditions can enhance TOWC degradation. Lastly, the media provides tremendous trace organic contaminant adsorption/absorption potential. The primary objective of this project is to evaluate the removal of trace organic contaminants as domestic wastewater is being renovated by RPBMBs. We will gain insight as to the removal mechanisms.

The specific objective of this project is to determine whether the combination of endogenous respiration and reducing conditions found in a RPBMB can maximize the biodegradation of TOWCs found in domestic wastewater. Using a series of laboratory-scale RPBMB, the removal of seven commonly found TOWCs will be monitored. The TOWCs will include triclosan, bisphenol-A, ibuprofen, diclofenac, naproxen, sulfamethoxazole, and 17α-ethinylestradiol.

Methods, Procedures and Facilities:

Four laboratory-scale recirculating media biofilters have been assembled. Each system includes a supply tank (septic tank effluent), a column filled with media (3-5 mm fine gravel), a recirculation tank and a final product tank. Primary-treated wastewater from a community-scale decentralized treatment system serves as the wastewater source. The supply tanks emulate the discharge from primary treatment (liquid/solid separation) and feed into the recirculation tank on a diurnal basis – representing higher wastewater flows that occur during mornings and evenings. Effluent in the recirculation tank is then micro-dosed to the column four times per hour. The discharge of the column flows through a three-way valve that determines whether the effluent flows back to the recirculation tank or to the final discharge. The recirculation rate is five to one. Every fifth time the recirculation pump doses the column, the three-way valve switches state, and the column effluent drains to the final discharge.

All system components have been manufactured from stainless steel, glass, or coated with polytetrafluoroethylene (PTFE) in order to minimize the partitioning of the trace organic compounds to the system surfaces. Four of these systems have been constructed to provide three replicates and one non-OWC control. Each system received primary treated wastewater for 20 days to establish the biofilm within the media. BOD and COD analyses were used to confirm that the biofilm was established and metabolically active.

Figure 1. The experimental setup for determining the removal of trace organic compounds by packed-bed recirculating media filters. The right-side glass jar is the recirculation tank and the left-side jar is the final product – a three-way valve under each column directs the effluent to the appropriate jar. The diaphragm pump is used to recirculate the effluent.

At this time, the wastewater is being spiked with 1 ppm of triclosan, ibuprofen, and diclofenac. The recirculating media biofilters will receive this dosage for 60 days. Prior to initiating the experiments, the concentration of the selected organic contaminants in the primary treated effluent was determined. During each experiment, the concentration of the selected contaminants was measured in the spiked effluent, the recirculation tank, and finished product. In order to determine if there are changes in the microbial communities due to metabolizing the various TOWCs, biofilm samples from each treatment will be taken after 60 days of activity, and frozen. The DNA collected and purified from these samples will be subjected to phylogenetic analyses via 454 pyosequencing of 16S rRNA genes.

Information Transfer Program Introduction

INFORMATION TRANSFER PROGRAM

The major emphasis of the information transfer program during the FY 2013 grant period focused on technical publication support, conference planning/development, and improvement in the information transfer network. The primary purpose of the program was to support the objectives of the technical research performed under the FY 2013 Water Resources Research Institute Program.

The primary objectives, as in previous years, of the Information Transfer Activities are:

To provide technical and structural support to water researchers performing research under the WRRIP.

To deliver timely water-resources related information to water researchers, agency administrators, government officials, students and the general public.

To coordinate with various federal, state, and local agencies and other academic institutions on program objectives and research opportunities.

To increase the general public's awareness and appreciation of the water resources problems in the state.

To promote and develop conferences, seminars and workshops for local and state officials and the general public which address a wide range of issues relating to the protection and management of the state's water resources.

During the FY 2013 grant period, a major focus of the information transfer activities was on the participation of the Center staff in the planning and implementation of several statewide conferences and training workshops.

As a co-sponsor, the TNWRRC was involved in the planning and implementation of the Twentieth Third Tennessee Water Resources Symposium, which was held on November 4-6, 2013 at Montgomery Bell State Park in Burns, Tennessee. The goals of the symposium are: (1) to provide a forum for practitioners, regulators, educators and researchers in water resources to exchange ideas and provide technology transfer activities, and (2) to encourage cooperation among the diverse range of water professionals in the state. As with previous symposia, the twenty-third symposium was very successful with over 340 attendees and approximately 70 papers and 26 student posters being presented in the two-day period. The event received a good deal of publicity across the state.

TNWRRC and the University of Tennessee served as the primary sponsor and host university for the Water Education Summit 2013 held on September 24-26, 2013 at the Sheraton Read house in Chattanooga, TN. This annual conference has a focus on water resource challenges and ways to make a difference at the local level. It provides opportunities to network with and learn from leading educators working to improve several aspects of water resources protection and management. Through the many presentations, discussion groups, workshops and tours attendees learn about innovative approaches for using information, technology transfer and hands-on learning experiences to change behaviors and inspire water stewardship locally. The annual Summit is sponsored by the Southern Regional Water Program, which is a partnership of USDA NIFA and the Land Grant College and Universities. There were over 175 people from twenty-one states and seven countries attending the 3 day conference in Chattanooga.

TNWRRC was a co-sponsor of the Tennessee Stormwater Association Conference, What are You Wadin For?, held on November 12-14, 2013 at Henry Horton State Park. Over 126 attendees including staff from MS4 communities, state agencies, and engineering consulting companies from across the State participated in the 3 day event which included over 40 presentations, 4 hands-on workshops and several social networking sessions.

TNWRRC sponsored the Stormwater BMP Inspection and Maintenance Certification course held on November 20-21, 2013 in Nashville ,TN. Approximately 45 invited guests attended the pilot offering of the course, which will be part of the new Permanent Stormwater Training program which TNWRRC is developing with support from the TN. Department of Environment and Conservation (TDEC) and the TN Stormwater Association (TNSA). Faculty and staff from the University of Tennessee and North Carolina State University served as instructors for the tow day course.

The Center also participated in several meetings and workshops across the state that were held to address water related problems and issues such as stormwater management, water quality monitoring, non-point source pollution, water supply planning, TMDL development, watershed management and restoration, multiobjective river basin management and lake management issues and environmental education in Tennessee. The following is a brief listing of formal meetings, seminars and workshops that the Center actively hosted, supported and participated in during FY 2013:

East Tennessee MS4 Stormwater Management Working Group, July 24, 2013, October 25, 2013, January 21, 2014 at Knox County Stormwater Department, Knoxville, TN. TNWRRC and the Tennessee Department of Environment and Conservation sponsored a quarterly meeting of local government officials responsible of implementing local stormwater programs under the MS4 Phase II permit. These meeting are designed to provide local officials with information that will add them in development of their local stormwater management programs.

Tennessee Department of Agriculture, Nonpoint Source 319 Program Workshop, Ellington Agriculture Center, Nashville, TN. March 17, 2013.

Tennessee Wetlands Technical Advisory Task Force meeting, May 6-7, 2013, Nashville, Tennessee. Meeting of government agency staff and technical experts to advise to the State on issues related to the Tennessee Wetlands Management Plan.

WaterFest, May 2, 2013, Knoxville, TN. An annual community-wide event sponsored by the Water Quality Forum that highlights the importance of our water resources and the activities of the WQF partners to protect and manage those resources. Over 900 elementary school age students from the Knox County school systems and schools from the surrounding region attended.

Fundamentals of Erosion Prevention and Sediment Control for Construction Sites Level I Training workshops, sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. A one day course for developers, contractors, road builders and others involved with construction activities across the State. The course was offered on the following dates in FY 2013: March 5, 2013, Knoxville, TN.; March 21, 2013, Chattanooga, TN.; April 16, 2013, Memphis, TN.; May 2, 2013, Knoxville, TN.; May 7, 2013, Nashville, TN.; July 23, 2013, Nashville, TN.; September 11, 2013, Knoxville, TN.; September, 19, 2013, Nashville, TN.; October 8, 2013, Chattanooga, TN.; October 24, 2013, Memphis, TN.; November 6, 2013, Johnson City, TN.; November 19, 2013, Nashville, TN.; December 12, 2013, Knoxville, TN.; February 25, 2014, Nashville, TN.For this time period over 1,687 persons obtained Level I certification.

Construction Site Inspection as Required by Tennessee's Construction Stormwater General Permit - Level I Recertification course sponsored by the Tennessee Department of Environment and Conservation and the Tennessee Water Resources Research Center. This is a half day course which focuses on inspection requirement under the current TNCGP. This course is required for all inspectors of construction sites that have coverage under the TNCGP and serves as a recertification course for those that have completed the Level I Fundamentals course. The course was offered on the following dates: May 9, 2013, Nashville, TN.; May 21, 2013, Knoxville, TN.; May 22, 2013, Chattanooga, TN.; May 23, 2013, Nashville, TN.; October, 1, 2013, Knoxville, TN.; October 2, 2013, Chattanooga, TN.; October 3, 2013, Nashville, TN.; October 23, 2013, Memphis, TN.; November 7, 2013, Johnson City, TN.; November 12, 2013, Jackson, TN.; November 15, 2013, Murfreesboro, TN.; December 3, 2013, Memphis, TN.; December 10, 2013, Chattanooga, TN.; December 11, 2013, Nashville, TN.; December 17, 2013, Knoxville, TN.; January 25, 2014 Nashville, TN. (two sessions)For this time period over 2,786 persons obtained Level I Recertification.

Tennessee Hydrologic Determination Training (TN-HDT) program. This new training program was developed and is being offered to meet the requirements of Tennessee Code Annotated, Section 69-3-105 which establish standard procedures for making stream and wet weather conveyance determinations in Tennessee. The three day course was developed by staff from the Tennessee Department of Environment and Conservation (TDEC) and faculty from the University of Tennessee and Tennessee Technological University. TNWRRC is responsible for administration of the TN-HDT program and works with TDEC and university faculty to deliver the course three to four times each year at selection location across the State. The course was offered on August 13-15, 2013, at Montgomery Bell State Park

Partnered with faculty for Auburn University and North Carolina State University, University of Tennessee and the City of Knoxville and Knox County Stormwater programs to host the 2013 Watershed Academy: Water Resource Management from Downspout to River Mouth. The two day workshop targeted staff from MS4 communities in Tennessee and UT Extension county agents with a focus on watershed management basics and how to engage community partners in watershed restoration activities. The Academy included tours of LID stormwater management practices and urban stream restoration projects. Over 35 persons attended the Academy in Knoxville on July 13-14, 2013.

Adopt-A-Watershed teacher training workshop, June 11-13 2013, Knoxville, TN. This four day workshop sponsored by TNWRRC and partners of the Water Quality Forum trains middle and high school science teachers on how to work with their students to conduct watershed investigations and develop watershed improvement service projects and part of their classroom curriculum. Eight new teachers completed the training course in 2013.

Knoxville Water Quality Forum, Quarterly meetings, May, July and October 2013 and January 2014. Meeting of government agencies and other organizations to share information and discuss water quality issues in the Tennessee River and it's tributaries in Knox County.

Little River , French Broad River, Bull Run Creek, Beaver Creek Stock Creek and Emory River Watershed Associations, monthly meetings. Agency staff and community leaders working towards protection of the Little River, Lower French Broad, the Emory/Obed and smaller tributaries watersheds.

Joint UT-TVA-ORNL Water resources Consortium Seminar Series on timely water resources topics, issues and projects of common interest to the three organizations.

Other principal information transfer activities which were carried out during the FY 2013 grant period focused on the dissemination of technical reports and other water resources related reports published by the Center as well as other types of information concerning water resources issues and problems. A majority of the requests for reports and information have come from federal and state government agencies, university faculty and students, and private citizens within the state. The Center also responded to numerous requests from across the nation and around the world.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	10	0	0	0	10
Masters	9	0	0	1	10
Ph.D.	2	0	0	1	3
Post-Doc.	0	0	0	0	0
Total	21	0	0	2	23

Notable Awards and Achievements

Dr. John S. Schwartz, PE received the 2012 Research Recognition Award from the Department of Civil and Environmental Engineering, College of Engineering, The University of Tennessee, Knoxville, April 2012.

Publications from Prior Years

1. 2005TN17B ("Impacts of watershed urbanization on longitudinal fragmentation of stream habitat quality and fish habitat use") - Conference Proceedings - Schwartz, John and K.J. Neff,2013,Restoring Pool-Riffle Structure in Beaver Creek, Knox County, Using a Hydraulic Modeling Approach for Urban Streams, "in" Proceedings of the Twenty-Third Tennessee Water Resources Symposium,Tennessee Section of the American Water Resources Association, Nashville, TN. p.1B-40.
2. 2006TN29B ("Structuring of an Infromation Transfer and Outreach Strategy for TNWRRC Under a New Organizational Framework") - Conference Proceedings - Arthur, R.A.,and R.A. Hanahan,2013, "in" Proceedings of the Twenty-Third Tennessee Water Resources Symposiums, Tennessee Section of the American Water Resources Association, Nashville, TN. p.1B-37.
3. 2006TN29B ("Structuring of an Infromation Transfer and Outreach Strategy for TNWRRC Under a New Organizational Framework") - Conference Proceedings - Parker, Joe, J. Wodarek, and R. Arthur,2013, Green Infrastructure Conceptual Planning and Policy Development Using EPA's SUSTAIN Model, "in" Proceeding of the Twenty-Third Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN. p.1B-41.
4. 2008TN53B ("A Survey of Bank Erosion in Beaver Creek, Knox County, Tennessee: Correlations of Channel Stability with Force and Resistance Variables") - Conference Proceedings - Woockman, Robert, J. Schwartz, and C. Harden,2013,Use of Continuous Turbidity Monitoring Data to Identify Biological Impairment Due to Suspended Sediment in East Tennessee Streams, "in" Proceeding of the Twenty-Third Tennessee Water Resources Symposium, Tennessee Section of the American Water Resources Association, Nashville, TN. p.2C-18.
5. 2005TN17B ("Impacts of watershed urbanization on longitudinal fragmentation of stream habitat quality and fish habitat use") - Conference Proceedings - Schwartz, J.S., and K.J. Neff, 2013, A Hydraulic Modeling Approach to Restoring pool-Riffle Structure in an Incised, Straighten Urban Stream Channel, "in" ASCE/EWRI World Water & Environmental Resources Congress; Cincinnati, OH.,May 19-23, 2013.
6. 2008TN53B ("A Survey of Bank Erosion in Beaver Creek, Knox County, Tennessee: Correlations of Channel Stability with Force and Resistance Variables") - Conference Proceedings - Woodckman,R., J.S. Schwartz, and C. Harden,2013,Use of Continuous Turbidity Monitoring Data to Identify Biological Impairment due to Sespended Sediment in East Tennessee Streams, "in" ASCE/EWRI World Water & Environmental Resources Congress, Cincinnati, OH.,May 19-23,2013.